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Longisection through the crown of a rhubarb plant showing tissues affected by crown rot; the dark areas mark the parts invaded by the Phytophthora.

THE CROWN ROT OF RHUBARB CAUSED BY PHYTOPHTHORA CACTORUM

STATE COLLEGE, CENTRE COUNTY, PENNSYLVANIA

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A CROWN ROT OF RHUBARB CAUSED BY PHYTOPHTHORA CACTORUM

By

W. S. BEACH[1]

Part I contains facts of general interest concerning the disease including control measures. Part II is devoted to a more technical description of the cultural and morphological characters of the parasite and to the relation of crown rot to similar Phytophthora diseases of rhubarb in other states.

PART I

INTRODUCTION

In a previous report (3) the writer called attention to a Phytophthora crown rot of rhubarb found in Philadelphia County, Pennsylvania. Additional investigation shows that the parasite causing this disease is *Phytophthora cactorum* (Leb. & Cohn) Schroet., a fungus known heretofore in America mainly by its causal relation to a disease of ginseng (15, 16, 21, 30) and a rot of apples and pears (1, 20, 31, 33). The extensive killing-out this parasite has been observed to cause in certain rhubarb fields coupled with its widely reported distribution makes it desirable to point out the salient features of the disease and to present other interesting data resulting from the investigation, especially data indicating methods of control. This discovery of the attack of rhubarb by *P. cactorum*, while bringing to light another important host for the ubiquitous parasite, likewise helps to explain the dying of rhubarb in cases hitherto obscure.

PRELIMINARY INVESTIGATION

Killing-out, premature dying of the leaf stalks in summer, and the loss of vitality in numerous rhubarb fields attracted the attention of the Department of Botany of The Pennsylvania State College as early as 1915-17, principally through the observations of Professor C. R. Orton. The importance of the trouble and the lack of knowledge concerning the cause led to the matter being taken up in 1919 as a project for investigation at the research laboratory located in Bustleton, Pa. The project appeared the more worthy of attention on account of the seriousness of parallel and also uninvestigated troubles in other states (see Part II).

A review of the literature revealed that little was known about rhubarb diseases in which the roots or the crowns are decayed. The occurrence of the sterile fungus Rhizoctonia on rhubarb was reported (5, 8), and lately G. H. Godfrey, Pathologist, U. S. Department of Agriculture, as well as the writer, have found this parasite associated with a condition in which the tissues of the leaf stalks near the soil become characteristically mealy, and the leaf blades turn reddish-yellow and develop large necrotic areas. That this parasite is ever responsible for the death of rhubarb has not been noted, however, while, on the other hand, infection experiments with *Phytophthora* spp. have never produced the symptoms just mentioned.

Stevens (27) has described the anthracnose of rhubarb calling the causal organism tentatively *Colletotrichum crumpens* Sacc. Anthracnose, which is char-

[1]Contribution from the Botany Department, The Pennsylvania State College, No. 39.

acterized by numerous, brown, depressed lesions on the leaf stalks, occurs commonly in Pennsylvania, usually in late summer, and upon superficial examination this disease may appear to be the real cause of the death of the rhubarb. Inoculation experiments, however, show that this fungus is able to infect only detached or old leaf stalks of impaired vitality, indicating that the organism is a very weak parasite. In this G. H. Godfrey (9) and the writer have obtained very similar results. Anthracnose, therefore, merely accompanies crown rot or any other condition lowering the resistance of the host; compare the illustrations Plate I, Figs. 3 and 4 with Plate III, Figs. 6 and 7.

Certain workers who have examined specimens of rhubarb where killing-out has occurred have been of the opinion that the trouble is bacterial* (29). Species of bacteria and also of Fusarium are found abundantly in and upon decaying tissues, but repeated inoculation experiments by the writer with pure cultures of such organisms have so far proved none of them to be more than saprophytes. The closeness with which these saprophytes follow the invasion of the Phytophthora has led to confusion, and the real parasites have no doubt been overlooked frequently.

The Isolation of Phytophthora cactorum — During August 1920, the locality embracing the intensive trucking section tributary to the city of Philadelphia experienced a prolonged period of wet cloudy weather, which greatly favored the disease under investigation and resulted in the death of continuous areas in the troubled rhubarb fields. When some of the dying plants were being dug, attention was drawn to the brown discoloration of the roots, secondary as well as primary, to a depth of 6 to 8 inches below the surface of the soil; Plate III, Fig. 8. The rapid advancement of the rot no doubt made these features outstanding. Tissue fragments were taken from the interior of such roots, near the border line of discoloration, the usual aseptic precautions being employed, and the fragments placed on corn-meal agar plates. Within a few days some fungous colonies, different in appearance from any obtained in numerous former procedures, were observed growing beyond bacterial contamination. The formation of oogonia and antheridia was noted, and later conidia typical of Phytophthora appeared. Pure cultures were obtained from transfers taken at the edge of the colonies. Suspicion was cast upon this Phytophthora as being the real pathogene, and infection experiments have proved beyond doubt that such is the case. Immediate microscopic examination of free-hand razor sections of various discolored tissues from roots, buds, and petioles collected in different diseased fields, disclosed the frequent occurrence of a gnarled, coenocytic mycelium in the affected parts.

DAMAGE AND DISTRIBUTION BY PHYTOPHTHORA CACTORUM

In the territory adjoining Philadelphia, rhubarb culture includes several hundred acres, and the crop is considered a very profitable one. In a number of instances, however, *Phytophthora cactorum* has destroyed the stand to such an extent that the affected fields no longer have been worth continuance. The important loss usually occurs in new plantings, a fact also observed in Illinois. Apparently the practice of cutting apart old crowns for setting new hills makes possible the easy entrance of the parasite through the wide wound surfaces, the principal source of infection appearing to be comparatively few diseased plants in the old field from which the crowns were taken. The loss that may occur under such conditions is illustrated by the accompanying map, Fig. 2, which represents a typical portion of a new field as it appeared in late September, 1921.

* See footnote (2) p. 15.

This field was set the previous spring with crowns taken from a place where the disease existed, although the loss had not been serious.

According to this map, only 46.1 per cent of the hills have healthy and vigorous crowns that will yield well the following spring. There are 10.7 per cent with weak crowns in which a considerable part has been rotted by the Phytophthora during the recent summer but with partial recovery, or in which there seemed to be a lack of vitality due possibly to the effects of the disease in

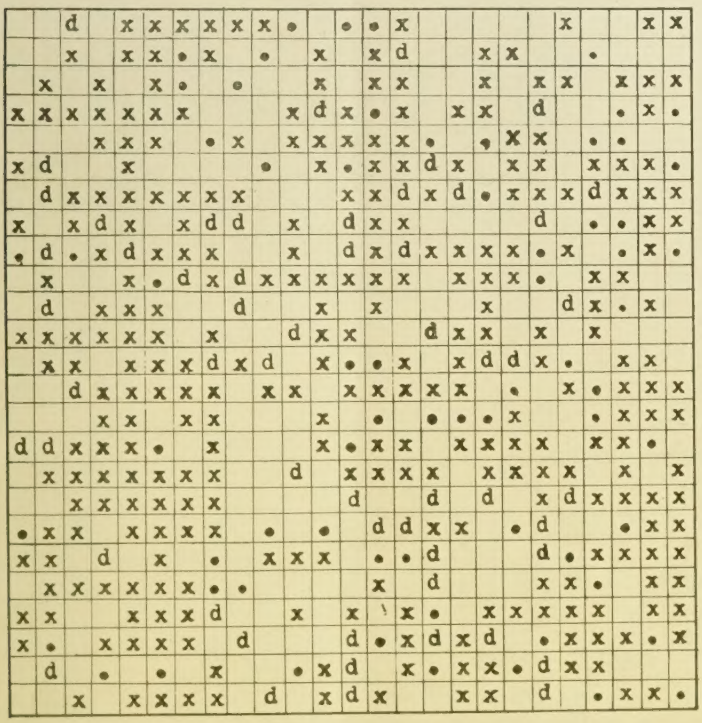


Fig. 2. A map of a portion of a newly established rhubarb field infested by *Phytophthora cactorum*. The map was made in late September when the disease had ceased to spread.
(X) Indicates strong healthy plants, 46.1%.
(d) Indicates diseased plants, 9%.
(•) Indicates weak plants, disease in most cases having been present, 10.7%.
Blank squares indicate dead plants, 34.2%.

former years. Diseased plants in which typical symptoms were still clearly perceived comprise 9 per cent of the stand. These plants developing disease so late in the season may recover sufficiently to become more or less productive the next year. It is probable that such plants are the leading sources of future infection, since they cloak the disease. The blank squares comprise 34.2 per cent and represent plants that succumbed to the crown rot, or in not a few cases, appeared to die soon after planting for want of vigor. Killing-out in older fields is comparatively slow; plants that survive the setting-out season in a vigorous condition appear more able to withstand future attacks of the disease.

PLATE I

Fig. 3. A photograph of a rhubarb field in early August (1921) showing wilting leaf blades on large plants, the first symptoms to indicate that *Phytophthora cactorum* is working in the crowns.

Fig. 4. A large seedling rhubarb plant killed by inoculation with *Phytophthora* sp. isolated from diseased rhubarb specimens from Illinois. A suspension of conidia with mycelium was poured into the center of the crown on July 29, and the photograph shows the plant on Aug. 6. It may be noted that no lesions of Colletotrichum or any other fungous infections are present on the aerial parts of the plant.

PLATE II

Fig. 5. The most common type of lesions caused by *P. cactorum* upon rhubarb petioles. During damp weather the conidial fructifications of the Phytophthora may be found upon the surface of such lesions as clusters of conidiophores emerging through the stomata. These are natural infections, and secondary organisms have not as yet attacked the upper stretches of the petioles or the leaf blades. Aug. 1921.

The owner of the field where the map was made had a similar experience in 1920 with a new setting of rhubarb, the stock coming from the same source as in 1921. On five other farms of the locality, the author has noted comparable losses in starting new fields, from a quarter to a half of the stand dying or having many crowns of repressed growth where only a bud or two survived the disease. In each case, *Phytophthora cactorum* has been found associated with the trouble. That the fungus does not seem to occur in the majority of rhubarb fields, however, was shown by search and by the fact that new plantings made from the division of old healthy crowns gave perfect stands.

Definite data upon the geographic distribution of *P. cactorum* on rhubarb are relatively meagre, inasmuch as the relation of the fungus to crown rot is a matter of recent discovery. The parasite has been observed in Philadelphia and Delaware Counties, Pa., by the author. G. H. Godfrey* stated verbally that he found in the vicinity of Washington, D. C., during 1921, a Phytophthora in diseased rhubarb that agreed in character with the cultures sent him from Philadelphia, indicating that *P. cactorum* is present in that locality. In late summer of 1921, Dr. H. E. Thomas found *P. cactorum* in rhubarb taken from the horticultural gardens at State College. Assuming that *P. cactorum* as found upon ginseng or apples passes over to rhubarb — and some experimental data indicating this have been obtained — it appears probable that the crown rot of rhubarb caused by this fungus has as wide a range as the Phytophthora diseases of these previously known hosts. Rosenbaum (21) states that the mildew in ginseng probably exists in every state in which the plant is grown — Washington, Oregon, Nebraska, Kansas, Missouri, Arkansas, Wisconsin, Minnesota, Michigan, Indiana, Ohio, New York, Pennsylvania, New Jersey, and Maryland.

THE DISEASE

The first obvious indication of infection by *Phytophthora cactorum* in the crown of a rhubarb plant is the wilting of a leaf blade or a few leaf blades, as illustrated in Plate I, Figs. 3 and 4. If the weather is damp, the blades droop with the edges commonly rolling inward; if the weather is dry, the blades may droop and shrivel. As wilting progresses in the blade, the leaf stalk loses turgidity so that the entire leaf structure falls prone on the soil. This phenomenon may begin in any leaf old or young, and frequently it is observed in one of the youngest just unfolding the blade. During warm muggy weather of summer, the symptoms are rapid in development and spread to other leaves, resulting in the collapse of all aerial parts of the plant in the course of a few days. In some cases only a section of a crown, a bud or two with the accompanying leaves, may succumb at one time, the rest of the plant appearing healthy until another rainy period gives the disease new impetus.

If a plant in an advanced stage of wilt is dug and a longi-section made through the crown, a condition like that in Fig. 1, frontispiece, is revealed. Extensive portions of tissue in the primary roots, in the buds including the suppressed stem, and in the lower ends of the leaf stalks have a brownish-black discoloration, which is in distinct contrast with the normal tissues, usually yellow or light yellow. The abnormal color marks the line of invasion by the Phytophthora mycelium. On the sections of the leaf stalks enveloped in the crown, there develop brown depressed lesions, which may be examined by merely pulling the stalks; Plate II, Fig. 5. The fungus usually does not advance far

* See footnote (1) p. 15, Part II.

into the petioles, and there may be no sign of rot above ground other than a blackened bud or a petiole lesion just at the surface of the soil. Continuous rainy weather occasionally makes possible the infection of young leaf blades or the upper parts of petioles, but ordinarily the aerial parts wilt and collapse on account of the destruction of the crown and roots.

The rapidity of the wilt, including the young leaves, and the discoloration of the buds as well as other tissues of the crown, are early symptoms that distinguish the crown-rot most readily from minor rhubarb diseases, especially from that caused apparently by Rhizoctonia, or from effects brought about by secondary organisms. In Plate I, Fig. 4, the destruction of the plants was sudden, and it may be noted that at first the upper portions of the petioles and the leaf blades may be free of any spots or lesions indicating attack by an organism. But when cut off from the roots, the leaves are naturally attacked by a great number of saprophytes, undergoing final decomposition as would any other detached plant part. The tissues invaded by the Phytophthora are in the beginning not greatly softer in texture than healthy tissues, but the immediate following of saprophytes soon brings about the complete disintegration of the affected parts. As previously mentioned, the most outstanding among these secondary organisms is the Colletotrichum, which is confined chiefly to the petioles. The secondary decay of the interior of the crown and roots, however, results more from the action of species of bacteria, Fusarium, and other molds.

A study of the map, Fig. 2, will show that centers of disease develop and spread, resulting in the death of groups of plants. Occasionally, with weather favoring the disease, such centers become rods in width, and the final aspect of the stricken areas is given in Plate III, Figs. 6 and 7. One may note the shriveled and decomposing leaves, and with close inspection discern the lesions of anthracnose. If the dead hills are dug into, one discovers at some depth, pieces of roots more or less intact, the upper portions manifesting Phytophthora rot, the lower portions retaining normal color and seemingly healthy; Plate III, Fig. 8.

Here and there in late September, an apparently dead crown may put forth a few weak leaves, showing that certain buds, often adventitious, escape the rot during its active period. Normally in southeastern Pennsylvania, rhubarb tops do not die down until late October and, during the interval elapsing between the checking of the disease and the conclusion of the growth of the season, many enfeebled survivors attain a degree of recovery depending upon the original inroads of the crown rot. An examination of such surviving plants in late fall discloses practically all healthy portions separated from decayed portions by the development of callous tissues. Numerous new buds have formed, which in spring send forth spindling leaf stalks scarcely fit for market.

THE RELATIONSHIP OF SEASON AND WEATHER

In 1921, the first symptoms of crown rot were observed in commercial rhubarb plantations a little before the middle of July, a series of rainy cloudy days occurring at this time, and it was after the middle of September before all activity of the disease ceased. During this period, the disease was most prevalent and pronounced in its symptoms from July 29 until August 20. Between these two dates, there was precipitation on 10 days amounting to 6.74 inches, and 11 days were more or less cloudy. The period of greatest disease activity in 1920 extended throughout the month of August, during which there was pre-

PLATE III

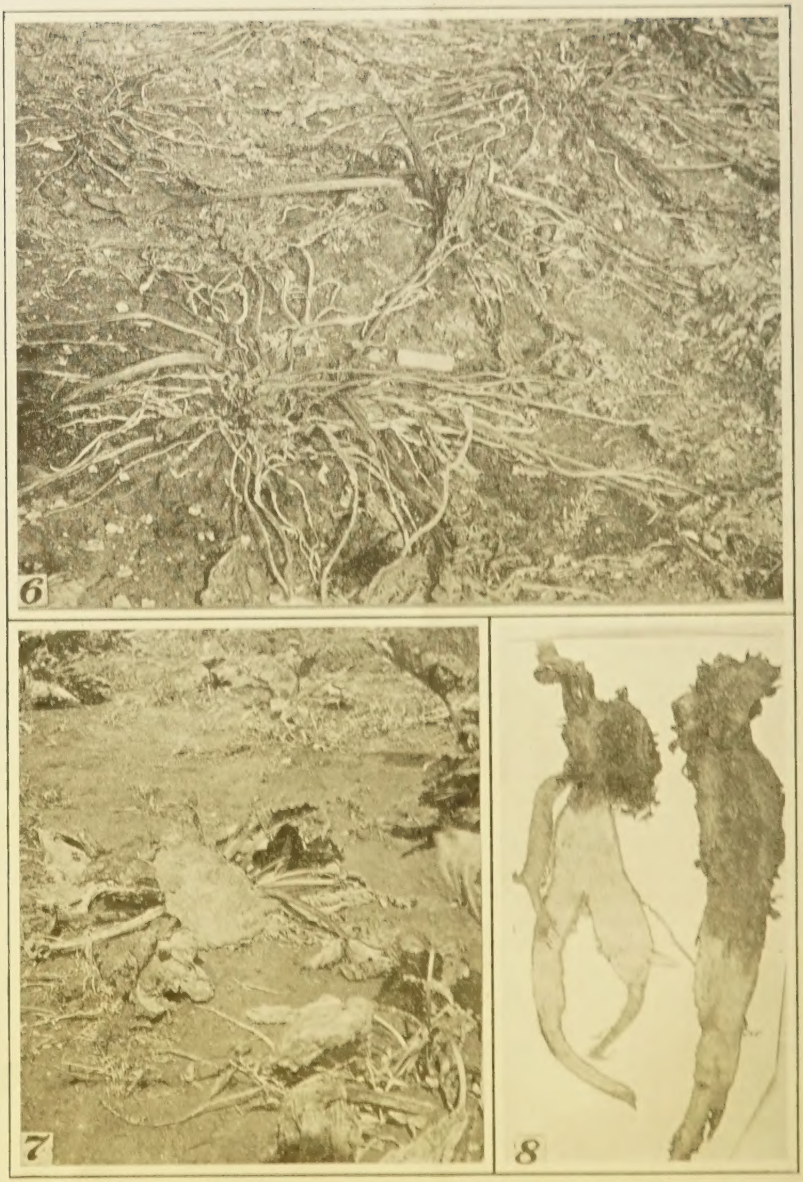


Fig. 6. Continuous area of a rhubarb field killed by crown rot. The leaf blades and petioles have been more or less completely decomposed by secondary organisms, Colletotrichum being much in evidence. Aug. 29, 1920.

Fig. 7. An intermediate stage in the death of a plant by crown rot accompanied by a severe outbreak of anthracnose (Colletotrichum) August, 1919.

Fig. 8. Longisections of rhubarb roots dug in a killed-out area like that shown in Fig. 6. The crown rot has destroyed all buds and has progressed downward a considerable distance into the main roots, but the lower portions of the roots have natural color and the tissues appear healthy.

Fig. 9. A large rhubarb plant in which the six oldest petioles have been inoculated through wounds with *P. colocasiae*. As the weather was dry, the fungus progressed slowly but the gradual invasion of the petioles has caused the leaf blades to wilt and shrivel. See Table I A, experiment *h*.

Fig. 10. The photograph shows a new rhubarb field in early June where the plants used for setting had been affected to many cases with crown rot the previous season. Many excess plants have died or lack vitality. Crown rot appeared later in the summer and caused additional loss.

cipitation on 19 days totaling 8.36 inches and 25 days were more or less cloudy. It was this period of weather that made possible the killing out of the continuous areas illustrated in Plate III, Fig. 6. That the crown rot is closely linked with wet cloudy weather, particularly when such weather occurs in prolonged periods, is clearly manifest.

In rhubarb crowns where the fungus has become established during a damp period, however, the disease continues to progress more or less actively throughout the drier intervals, the petioles one after another slowly evincing the characteristic symptom of wilt. That any season may have such prolonged drought as to preclude the development of the crown rot seems probable; yet the disease has been evident to some degree in the vicinity of Philadelphia during each of the seasons from 1918 to 1921. In the four years, the damage was greatest in 1920 and least in 1918, one summer being very wet and the other very dry during the critical time for disease development.

Rosenbaum (21) states that in the case of ginseng the most favorable time for infection by *P. cactorum* is in the early spring just as the new shoots are pushing through the soil. How early infection may occur in rhubarb has not been investigated in nature, but no difficulty was met in securing infection in April upon both roots and petioles of rhubarb forced under sash. It is probable that the fungus becomes established in rhubarb crowns much earlier than indicated by the first symptoms of wilt in the leaves, the size and the vigor of the host enabling it to withstand the inroads of the parasite during the cool spring months.

THE INFLUENCE OF DRAINAGE, SOIL AND FERTILITY

According to field observations, crown rot is able to assume severe proportions on well drained soil, although heavier losses occur on low wet areas. The part of the field shown in Fig. 2 is on a hillside. The physical character of the soil appears to have no influence except as it tends to increase the water-holding capacity. On rich, fertile soil, however, the rhubarb plants appear better able to withstand the disease since the host, on account of greater rapidity and vigor of growth, is more able to keep abreast of the parasite or recover from the injury inflicted.

THE CONTROL OF RHUBARB CROWN ROT[1]

The most effective control of a disease is possible only by an intelligent understanding of the cause and the conditions favoring its development and dissemination. *Phytophthora cactorum* on rhubarb is enabled to live from year to year, for the most part, probably, by means of the oospores, the winter or resting reproductive bodies, which germinating in the spring give origin to new infections. The writer found mycelium during early spring in old decayed parts, indicating that the fungus may pass the winter in this condition, but it was not proved that this mycelium was alive. The oospores may be found in the decayed tissues of the dead or partially rotted crowns, and Hartig (12) states that such spores in the case of the beech seedling disease may remain viable in the soil for four years. If the parasite has destroyed only a portion of the crown during the previous season, such a plant becomes a dangerous source of infection,

[1]In connection with control experiments and studies upon the crown rot of rhubarb, the writer is especially grateful for the kindness and cooperation of the following farmers of Philadelphia and Delaware counties, Pennsylvania: Wm. G. Wenker, Bustleton, Pa.; Jesse Livezey, Tacony, Pa.; Wm. B. Farrell, Frankford, Pa.; Thorvald Rasmussen, Folcroft, Pa.

especially if it is divided and used in setting a new field. The division of the crown through cutting creates great wound surfaces whereby the mycelium arising from the germinating oospores may gain easy entrance to the host tissues. The infection experiments given in Table I bring out the importance of wounds to infection — it appearing very difficult or impossible for the fungus to enter perfectly sound roots, although the healthy tissues of the buds, petioles, and leaf blades are susceptible during the warm, humid periods of summer.

A noteworthy fact in connection with the rhubarb crown rot caused by *Phytophthora cactorum* is its persistence in stock that has once become infected causing the gradual dying of plants in fields set before infestation became widespread, and rendering it impossible thereafter to start new fields without a very heavy loss of stand. When a grower is confronted with this situation, it is advisable to abandon the stock and obtain new roots from a source free of disease. Such disease-free roots should then be set in soil that has never grown rhubarb, or at least has not grown it for a considerable period of years. On most farms this is possible since the location of a rhubarb field is not often changed, frequently lasting eight to ten years, barring disease, and as already pointed out infestation is not met in the majority of places. The avoidance of the disease by the use of healthy stock appears of paramount importance in the establishment of new fields.

While the avoidance of crown rot by the aforesaid precautions may prove satisfactory in a great many cases — the occurrence of *P. cactorum* lending itself to such control — it is realized that conditions may become such that it would be difficult to find either entirely healthy roots or disease-free soil. The fungus is known to be rather ubiquitous, and the continuous and intensive culture of the host in a locality may eventually permit the parasite to become generally disseminated and established. This appears to be the case with the "root rot" in Union County, Illinois, there being considerable evidence that it is a Phytophthora disease. Under such conditions, additional methods of control in the way of protective sprays, sterilization of the roots and soil, rogueing and sanitary practices become necessary. Since an understanding of these Phytophthora diseases of rhubarb has been attained only recently, recommendations for control based on extensive experiment are not available. However, experiments so far indicate that copper fungicides will be of some benefit in preventing the spread of the disease.

Bordeaux spraying — During the season of 1921, standard Bordeaux spray of 4-4-50 strength was tested in a commercial field near Bustleton, Pa., for its power to check the spread of the crown rot. The first application was made to coincide with the close of the pulling season, and was applied July 18. This was probably too late from the standpoint of disease prevention for at this time 2.5 per cent of the hills were already showing slight evidence of crown infection. A knapsack type of pressure sprayer was used and the nozzle was directed into the crown, an effffort being made to reach the leaf axils, the lower sections of the petioles, and the adjacent soil. A second application was made on August 9. The sprayed plants comprised 150 hills and were situated in a known disease center where a few plants had previously died. Twelve gallons of spray were used in each application. A final survey was made on September 28 and the results were as follows:

Sprayed hills that died	6.5%	Check hills that died	8.6
Sprayed hills developing disease	.7	Check hills developing disease	5.9

An analysis of the results in the field indicated that the fungicide prevented the infection of further hills subsequent to the time of the application of the spray, but did not prevent the further rotting and death of hills in which infection was probably already established.

Inasmuch as *Phytophthora cactorum* is classed with the downy mildews, it would be expected that the fungus would be quite amenable to control by copper fungicides. The fact, however, that the region of attack upon the host is for a great part imbedded in the soil adds certain difficulties, it being impossible to stop the inroads of the parasite when it is once established in a plant. Whether it is feasible to spray producing fields during the market season should be determined, but in newly set fields there is no reason why spraying may not be started as early as April; and it now appears important to begin this soon (a) to prevent the first infections which probably occur early and (b) to safeguard the divided crowns that are unusually susceptible to infection through the wound surfaces.

Roguing — Since infected hills are rather certain to die before the close of a season, and their presence is a menace to surrounding healthy plants, it is important to remove the first occasional diseased plants appearing in the early summer. Such removal should be carefully done without scattering adhering soil, and the diseased roots should be burned. The soil of the hill for a radius of at least two feet should then be disinfected with formaldehyde solution, 1-100 of the commercial 40%, applying a gallon to a square foot. A healthy plant may then be set in 10 days if the season is not too late. Such roguing methods seem particularly important if it is known that the disease has been recently introduced. The permanence of the crop is also a consideration.

Root disinfection — Rhubarb roots for the purpose of establishing a new field may be disinfected, if in a dormant state, in order to destroy oospores that may be lodged in adhering soil or previously rotted host debris. Mercuric chloride 1-1000 or formaldehyde solution (a pint of the commercial 40% to 30 gallons of water) may be used, immersing the roots for one-half hour followed by rinsing in clean water. This is a precaution in case infestation is suspected.

Disease-free plants from seed. — A line of crown rot control that may be readily suggested is disease-free plants grown from seed. Such plants might be transplanted with a minimum amount of injury to non-infested soil, thus almost eliminating the likelihood of infection. There is, however, a practical difficulty for the rhubarb grower in this procedure, for most seed at present would produce many undesirable types of plants. No doubt a process of close inbreeding can develop a true-breeding strain of seed that will produce seedlings having all desirable qualities, but this would involve a large number of experiments. The survival of vigorous plants amid disease conditions points to the possibility of developing a disease-resistant strain of plants by selection.

Earliness in transplanting. Data upon farm practices at Bustleton, Pa., during 1922 shows that earliness in setting out infested rhubarb roots is a very important factor in reducing the loss by disease the first season. In one diseased field missing hills were reset March 29, while in another diseased field they were reset April 16. In the former case less than 10 per cent died by August 1, but in the latter nearly all died before this date. Doubtlessly, there is a great advantage to the host plant in becoming established before the parasite becomes very active. In this respect, good culture and fertilization are favoring influences.

PART II

TECHNICAL ASPECTS OF RHUBARB CROWN ROT AND ITS CAUSAL ORGANISM

OTHER PHYTOPHTHORA DISEASES OF RHUBARB

Current investigation has revealed the existence of two other species of Phytophthora besides *P. cactorum* that parasitize rhubarb. This fact has influenced to a considerable extent the present publication, among other things its date,[1] for another worker, G. H. Godfrey (9) is describing a Phytophthora rot of rhubarb almost identical in outstanding symptoms with that caused by *P. cactorum*. This author calls his disease "foot rot" and describes the parasite as *P. parasitica* var. *rhei* n. var.

Early in 1921 it became known by an exchange of cultures that this "foot rot", which is found in the vicinity of Washington, D. C., involves a Phytophthora different from the one near Philadelphia. The importance of finding characters that would distinguish diseases caused by such closely related fungi was evident. During the following summer, comparative infection experiments and field studies were made, but it was found that the two parasites produce essentially similar symptoms, there being no important distinctive characters whereby one may determine with ease and certainty the species of Phytophthora present. Certain environmental factors, however, temperature especially, have somewhat different effects upon the separate species, for unlike adaptations are manifest in dissimilar rates of development and spread of the diseases, and in dissimilar prevalence at various periods of the season. Although the varied comparisons brought out no striking contrasts, it is worth while to make a record of them.

In an effort to determine the distribution of the disease caused by *P. cactorum*, but more particularly to ascertain whether a species of Phytophthora might not be the cause of a serious rhubarb "root rot"[2] of obscure etiology in southern Illinois, some typical specimens of this disease were obtained from the vicinity of Anna, Union Co., Ill.[3] The symptoms disclosed in these specimens conformed in all essential respects with those produced by *P. parasitica* var. *rhei* or by *P. cactorum*. Affected tissues contained the mycelium of a Phycomycete, which upon isolation and study proved to be a species of Phytophthora unlike either of the two already noted. Infection experiments with pure cultures of the fungus showed that it had marked powers to infect and rot rhubarb, making it appear very probable that the organism is the cause of the destructive rhubarb malady in the mentioned locality.

[1] It has been the plan of G. H. Godfrey, Pathologist, Bureau of Plant Industry, U. S. Dept. of Agriculture, and of the writer to have the two publications on these Phytophthora diseases of rhubarb appear simultaneously if possible.

[2] The writer became familiar with this rhubarb "root rot" in Union County, Ill., by the perusal of copies of personal notes and letters of Dr. T. J. Burrill on file at the University of Illinois, the letters being dated 1912. These copies were furnished by Edwin E. Honey, who had made certain studies of the disease. For further information concerning the disease the writer is indebted not only to Mr. Honey but to Dr. F. L. Stevens, Professor of Plant Pathology, University of Illinois, who once suggested the disease as a problem for a doctorate thesis to the writer. At that time it was thought to be a bacterial disease.

[3] These specimens of the rhubarb "root rot" were selected and sent to the writer by F. A. Buerbaum, assistant adviser of the Union County Farm Bureau, Anna, Ill.

The identity of this Illinois Phytophthora has not been established since cultures of the fungus have consistently failed to produce oospores. It is very unlike *P. cactorum*, but is rather similar to *P. parasitica* var. *rhei* in growth characteristics and in the size of the conidia and chlamydospores. There are distinctions, however, especially the more elongate and pyriform shape of the conidia, that indicate quite certainly a different species. A mention of the discovery of this third species of Phytophthora parasitizing rhubarb is made at this time since the symptoms of the Phytophthora rots of rhubarb in various localities appear to be more or less alike, and the "root rot" in Illinois probably represents the most destructive case of the disease. But since both this causal organism and this disease require further study, a comprehensive discussion of them must await a later publication.

Recently Sherbakoff (26) has reported the occurrence of a Phytophthora disease of rhubarb at Knoxville, Tenn., stating that the fungus closely resembles *P. terrestris* Sherb. in gross morphology and in pathogenicity to tomato and rhubarb. Godfrey (9), however, suggests that this species should be referred to *P. parasitica*, and no doubt the disease is similar to the one Godfrey has studied.

Godfrey (9) in his paper has indicated the probable wide occurrence of the Phytophthora diseases of rhubarb. Dr. J. A. Elliott stated verbally to the writer that a rhubarb disease conforming to the description of Phytophthora rot is found in Arkansas. The writer also received from St. Louis, Mo., specimens of diseased rhubarb in which existed the mycelium of a Phycomycete, but decay and contamination were so advanced that it was impossible to isolate and determine this mycelium.

The situation requires considerably more investigation in a number of localities before the relative importance, the distribution, and the taxonomy of the species of Phytophthora on rhubarb can be ascertained. No particular significance needs to be attached to any one of the three common names, except for the differences in the organisms involved. Since the investigations here recorded are relatively local and concern mostly *P. cactorum*, this species alone can be adequately discussed in the present paper.

PROOF OF PATHOGENICITY

Infection Experiments. — The infection experiments made with *Phytophthora cactorum* from rhubarb are shown in Table I, A. Part B. of the same table shows results obtained with *P. parasitica* var. *rhei* Godfrey, Part C the results obtained with the species of Phytophthora isolated from the diseased rhubarb specimens from southern Illinois, and Part D the results with a culture of *P. cactorum* received from the Department of Plant Pathology of Cornell University and isolated from apple. The various results have been brought together for comparison.

The small rhubarb seedlings inoculated in the fall of 1920 were two to three months old and were grown from seed sown in flower pots, the latter being kept under cold frame sash. The large seedlings used during the summer of 1921 were started from seed sown in the garden in early spring. By rapid growth these acquired considerable size, becoming nearly equivalent to older plants in respect to petioles by August. The rhubarb plants referred to as "large" were set in the garden in 1919 and possessed extensive and vigorous crowns.

Phytophthora cactorum from rhubarb caused virulent infection in practically all instances in which the fungus was inserted in wounds and commonly the

Table I A. Infection Experiments with Phytophthora cactorum isolated from Rhubarb
Proof of Pathogenicity to Rhubarb

No. of Experiment	Part and Condition of rhubarb host	Method of inoculation	Environment or weather	Date begun	Date ended	Results
No. 1	Five seedlings with 2-3 leaves	Bit of culture inserted in stem wound	Under cold frame sash	10-14-20	10-21-20	All plants wilted, finally dying
Check to No. 1	As above	Wounded but without fungus	As above	10-14-20	10-21-20	Plants remained healthy
No. 2	Six petioles on large plant	Bit of culture inserted in wounds	In garden, mean temperature 59° F.	10-14-20	10-31-20	Lesions 2-3 inches long developed
Check to No. 2	As above	Wounded but without fungus	As above	10-14-20	10-31-20	Wounds scarred over, petioles remained healthy
No. 3	Young seedlings [illegible] in pots	Macerated cultures worked into soil	Under cold frame sash	11-1-20	11-21-20	No infection
No. 4	Young crown of a large plant	Bit of culture inserted in wound	Under cold frame sash	4-15-21	5-15-21	Extensive lesion developed involving crown
Check to No. 4	As above	Wounded but without fungus	As above	4-15-21	5-15-21	Plant remained healthy
No. 5	Six petioles on large plant	Bit of culture inserted in wound	In garden, bell jar for two days	6-13-21	6-30-21	Inoculated leaves wilted, disease spread to crown
Check to No. 5	Six petioles on large plant	Wounded but without fungus	As above	6-13-21	6-30-21	Petioles remained healthy
No. 6	Two main roots of large plant	Bit of culture inserted in wounds	In garden	6-13-21	8-15-21	Leaves wilting June 28, plant died in August
Check to No. 6	Two main roots on large plant	Wounded but without fungus	In garden	6-13-21	8-15-21	Plant remained healthy
No. 7	Axils of 12 petioles large plant	Bits of culture applied to epidermis	In garden, bell jar for two days	6-13-21	6-27-21	No infection, weather apparently too dry
No. 7a	Same parts of same plant	Above inoculation repeated	First three days rainy	6-27-21	7-10-21	Lesions formed on three petioles, disease did not enter crown
No. 8	Six petioles on large plant	Bit of culture inserted in wound	In garden, first three days rainy	6-27-21	8-3-21	Inoculated leaves wilting July 1, disease entered crown, killing plant

Table I A — (continued)

No. of Experiment	Part and Condition of rhubarb host	Method of inoculation	Environment or weather	Date begun	Date ended	Results
No. 9	Large plant with half the petioles [illegible]	Culture macerated in water and poured into crown	In garden, first three days rainy	6-27-21	8-3-21	Wilting began July 1, disease spread in crown, part recovered
[illegible]	Main roots of two [illegible]	Bit of culture inserted in wounds	In garden	7-1-21	8-15-21	Crowns rotted, plants died during August
[illegible]	Main roots of two [illegible]	Wounded but without fungus	In garden	7-1-21	8-15-21	One plant healthy, the other became diseased with crown rot
No. 11	Leaf surfaces of [illegible] large [illegible]	Suspension of conidia sprayed on	[illegible] rain [illegible] first two days, weather very favorable to disease	8-2-21	8-[illegible]-21	Large infected spots on leaves; infection carried to crown, [illegible] plants finally died; two adjacent plants became infected

Table I B. Infection Experiments with Phytophthora parasitica var. rhei Godfrey

No. 12	Main root of a large plant	Bit of culture inserted in wound	Under cold frame sash	4-15-21	6-10-21	Fungus spread little until June 1, low temperature of soil a retarding factor, plant killed; compare No. 4
No. 13	Axils of nine petioles, large plant	Bit of culture applied to epidermis	In garden, covered with box two days	6-13-21	6-27-21	Lesions on 7 petioles, disease spread to crown, killing plant in a few weeks; compare No. 7
No. 14	Six petioles on large plant	Bit of culture inserted in wounds	In garden, covered with box two days	6-13-21	6-27-21	Inoculated petioles wilted in 6 days, disease soon spread to crown killing plant by July
No. 15	Main roots of a large plant	Bit of culture inserted in wound	In garden	6-13-21	7-15-21	Large part of crown rotted in a few weeks, but a part recovered
No. 16	Main roots of two large plants	Bit of culture inserted in wounds	In garden	7-1-21	8-3-21	Signs of wilt in 8 days, one plant died in two weeks, the other before August

Table I C. Infection Experiments with Phytophthora sp. isolated from Rhubarb from Illinois

No. of Experiment	Part and Condition of rhubarb host	Method of inoculation	Environment or weather	Date begun	Date ended	Results
	three large seedlings	in wounds	ed with box two days. Weather very favorable to disease	7-29-21	8-7-21	Lesions rapid in development, leaves wilted in week, plants dead after ten days, disease spread to several nearby plants
	three large seedlings	to epidermis	ed with box two days. Weather very favorable to disease	7-29-21	8-7-21	Lesions rapid in development, same results as above, adjacent plants becoming infected via leaf blades and petioles

Table I D. Infection Experiments with Phytophthora cactorum isolated from Apple with Cultures from Rhubarb used for Comparison

	Two petioles on large seedlings	ple)	days	8-8-21	9-4-21	survived
	large plant	in wounds (from apple)	er used	8-8-21	8-14-21	Lesions formed on but two petioles causing wilt, disease did not spread to crown
	large seedlings	in wounds (from apple)	cover for two days, weather dry	8-8-21	10-4-21	cause death of petioles
	large seedlings	from rhubarb		9-8-21	10-8-21	
	seedlings	in wounds (from apple)		9-8-21	10-8-21	
				9-8-21	10-8-21	fore October

death of the host ultimately followed. Inoculation without wounding gave infection only under very favorable conditions of temperature and moisture, and then but a small per cent were positive. The failure of infection in Experiment No. 3, in which the fungus was placed about the roots of seedlings, wounding being avoided, does not seem to be explained altogether by unfavorable environment for the atmosphere was humid and the temperature, while low, was well within that required for the growth of the parasite. The moving of these inoculated plants, which were in pots, to a commercial greenhouse, where the temperature was more suitable, failed to bring out the disease. Taking into consideration the apparent relation of wounding to the severity of crown rot in rhubarb fields, it appears that the fungus is but little able to infect through perfectly sound roots. While both observations in nature and the general results of the infection experiments indicate that wounding is a very important factor in permitting new infections by *P. cactorum*, the parasite is quite able to make its entrance to the host through the healthy epidermis of leaves and petioles, provided moisture and temperature conditions are sufficiently favorable, as Experiments 7a and 11 demonstrate.

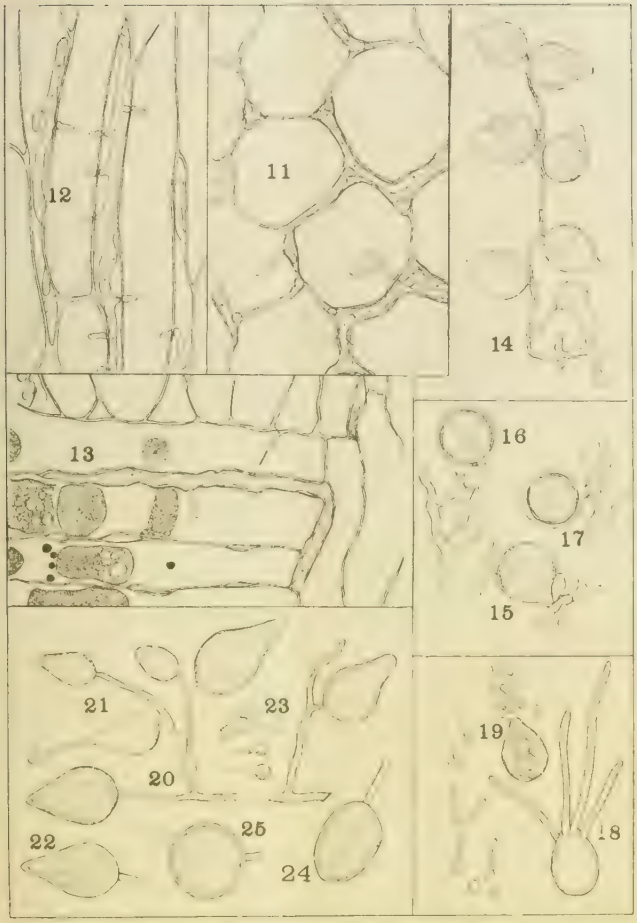
INFECTION PHENOMENA CAUSED BY PHYTOPHTHORA PARASITICA VAR. RHEI AND THE ILLINOIS PHYTOPHTHORA

With the higher temperatures of summer, *P. parasitica* var. *rhei* showed considerably greater power to infect rhubarb through the unwounded epidermis, judging by the results of experiments 7 and 13. Under like conditions, *P. cactorum* failed to infect while Godfrey's organism gave positive results in seven out of nine cases. The inoculations in question were made during a dry period, and in addition to covering the large plants with wooden boxes, a heavy watering was given in order to promote infection. The conditions, however, were not sufficiently favorable for *P. cactorum* to penetrate the healthy epidermis.

During the period of summer most favorable to the Phytophthora disease, infections by Godfrey's fungus developed and progressed more rapidly so that the host succumbed to the parasite in a considerably shorter time than was the case with *P. cactorum*. Judging by the relatively few infection experiments, this more rapid progress of disease is even more noteworthy in the Illinois fungus. One may interpret the results as indicating that *P. cactorum* is somewhat less virulent, still the instances in which the host ultimately died were almost as great with *P. cactorum* as with *P. parasitica* var. *rhei*. The latter, moreover, has a slightly greater tendency to spread to the upper parts of the petioles and leaves.

The few infection experiments with the Illinois Phytophthora were conducted during the most favorable disease conditions of the season, and were tried with and without wounding on the petioles, and by pouring a suspension of conidia into the crown. The fungus proved to be very parasitic and aggressive, appearing to infect as readily without wounds as where they were made. The inoculated plants stood at the ends of two rows of seedlings, and the individual plants were but a few inches apart. From the date of the inoculations, July 29, until the latter part of August, the disease spread along the rows destroying nearly a dozen plants in addition to those receiving inoculation. It was noted

PLATE V



(Magnification x 450 except where otherwise stated)

Fig. 11. Cross-section of parenchyma cells of a very young rhubarb petiole infected with *P. cactorum*. The hyphae of the parasite are at first chiefly intercellular and have typical haustoria that are knob-like to finger-like. Drawn from a fixed and stained section of 10 u thickness.

Fig. 12. Hyphae of *P. cactorum* in root tissue of rhubarb; tangential section near the border line of infection; fixed and stained section of 10 u thickness, x 325.

Fig. 13. Medullary ray cells of an infected rhubarb root showing hyphae of *P. cactorum* lying in a radial direction; fixed and stained section of 10 u thickness, x 325. The medullary ray cells of rhubarb each contain a number of brown semi homogeneous bodies whose function or composition has not been determined, although they appear to be excretory. These bodies may almost fill the cell lumen.

Fig. 14. A conidiophore of *P. cactorum* drawn from a growth on an agar hanging drop in Van Tieghem cell.

Fig. 15. Oogonium and antheridium of *P. cactorum*.

Fig. 16. Oosphere stage and fertilization tube in oospore development.

Fig. 17. Mature oospore, *P. cactorum*.

Fig. 18. Conidium germinating with germ tubes, *P. cactorum*.

Fig. 19. Conidium germinating by zoospores; also zoospores come to rest and germinating, *P. cactorum*.

Figs. 20-21. Conidia of the Illinois rhubarb Phytophthora attached to hypha like conidiophore.

Fig. 22. Conidium of the Illinois rhubarb Phytophthora showing the development of zoospores.

Fig. 23. Zoospores of the Illinois rhubarb Phytophthora motile, at rest, and germinating.

Figs. 24-25. Types of chlamydospores of the Illinois rhubarb Phytophthora.

that the first points of infection on adjacent plants were often on the leaves and upper sections of the petioles. From these points infection appeared to be carried into the central bud by rain water running down the petioles. In connection with inoculation experiments, *P. cactorum* was observed to spread to adjacent plants in only two instances, and these were cases of plants on the down-hill side from the seedlings receiving leaf inoculation on August 2. Disease first appeared in the main buds of the crowns, and conidia were probably splashed or carried along the sloping ground by rain water to the point of first natural infection.

DISEASE DISSEMINATION IN NATURE

The exact method of penetration by which *P. cactorum* gains an entrance to its rhubarb host has not been investigated in detail. The relation of wounds is mostly apparent, yet it appears so probable as to create little doubt. It is therefore likely that the germ tubes, arising from conidia or zoospores as the case may be, most frequently penetrate wounds created in pulling stalks for market and by the division of crowns as previously mentioned. Under very favorable weather conditions, however, it appears as if conidia are carried deep into the axils of petioles and the developing germ tubes penetrate the epidermis in many cases without the presence of wounds. Many centers of infection arise from the central part of the crown at a point that is not obvious without digging and sectioning the plant. As in the case of the ginseng disease, probably the conidia are carried about by wind, and by splashing and running rain water, thus making possible the infection of nearby healthy plants. Oospores lying in crumbling tissues previously attacked by the fungus are no doubt carried along the rows by cultivation. The occurrence of several consecutive plants developing the disease indicates this probability. The writer has observed definite cases where the disease has been introduced into new fields and farms by the presence of the fungus in the roots as oospores, and possibly as latent mycelium. A point requiring investigation concerns the time in spring and summer when the earliest infections occur. As mentioned the first symptoms appear during July, but infections probably precede this date by a considerable period. More data on this point are needed so that the time to undertake such control measures as spraying may be determined.

TEMPERATURE RELATIONSHIPS

The cardinal points of temperature for *P. cactorum* from rhubarb and *P. parasitica* var. *rhei* were determined for the light they might throw upon the varying disease phenomena and the probable geographic distribution of the two species. For temperatures above 18° C. an electric incubator was used, and for those below 18° C. some very constant temperatures were found in the water within a stone spring house and in that from the city water main at different times of the year. Oatmeal or lima-bean agars in tubes were used as culture media. It was found (Table II) that the temperature relationships of *P. parasitica* var. *rhei* and the Illinois Phytophthora are practically alike, the maximum being 36° C., the optimum near 30° C., and the minimum near 13° C. With *P. cactorum* the maximum is 33° C., the optimum near 25° C., and growth was still possible from 7-9° C. With *P. cactorum,* oospore production was found to be heavier below 20° C. than above, while the reverse was true for conidial production. The higher temperature adaptation of *P. parasitica* var. *rhei* indicates how it may outgrow *P. cactorum* during the hot periods of summer, but how the

latter may be enabled to develop earlier in the spring or later in the fall. The probability that *P. cactorum* has a more northern distribution is indicated, while the disease in the more southern localities is probably caused by the species having the higher temperature adaptations as thus far found.

THE RELATION OF PHYTOPHTHORA CACTORUM TO ITS RHUBARB HOST

All tissues of rhubarb exhibiting the typical Phytophthora rot are pervaded by the gnarled tubular mycelium. In the early stages of invasion, the hyphae follow the intercellular spaces, and their knob-like to finger-like haustoria, laterally produced, pierce the adjacent cell walls of the host; Plate V, Figs. 11, 12 and 13. In later stages of the rot the parasite multiplies its ramifications, and here and there knots of hyphae crowd the cells apart and not infrequently hyphal branches develop within the cells. In some cases one may note constrictions in the hyphae where they pierce the cell walls, but in other cases there is considerable dissolution of the cell walls, and no constriction is apparent. Dastur observed this latter condition with *P. parasitica* in the fruits of the castor oil plant (7, Plate II, Fig. 5). The cell structures appear to undergo considerable disintegration before the activity of secondary organisms is apparent; still the relative part played by the different organisms in late stages of decay is a doubtful point, although saprophytes are probably the more important. For the greater part, in rhubarb, the main mycelial strands lie in a longitudinal direction in relation to the host cells, both in the roots and the petioles. Between the medullary ray cells in the roots, however, many strands of mycelium lie in a radial position, showing that the medullary rays are commonly followed in the radial penetration of the fungus, (Plate V, Fig. 13). It has been observed that the rot in the petioles, where medullary rays are absent, progresses much more rapidly in a longitudinal direction than it does radially or towards the interior of these organs. In the roots, however, there appears little difference in this respect.

REPRODUCTIVE ORGANS OF THE PARASITE

Fructifications of *P. cactorum* upon rhubarb have not been observed abundantly. Oospores have been found but twice, notwithstanding the examination of a great deal of material. In one instance they formed upon a petiole placed within a large size test tube, and in the other they were found amid the crumbling host debris taken from an affected crown in the fall. This seeming rarity of oospores in affected tissues is peculiar, considering the reports of other investigators (19, 20, 21) as well as the prolific formation of these organs upon artificial media. The early entrance of secondary organisms or the composition of the host, may have deterrent effects, yet it is more probable that many oospores are formed under conditions not at present discovered.

Conidia are always produced during damp weather of summer upon the surface of those petiole lesions appearing above the soil, the lesions illustrated in Plate II being examples. If one strips the epidermis from the surface of such lesions and places it upon a glass slide without a cover glass, microscopic examination reveals a thick network of mycelium within and beneath the epidermal cells and appearing to be sub-cuticular as well. Emerging from the stomata are fascicles of conidiophores, each individual conidiophore being sparingly branched and bearing but a few attached conidia. Numerous detached conidia, however,

lie scattered upon the epidermal surface. Conidiophores emerging between epidermal cells or directly piercing the cuticle in the manner illustrated by Rosenbaum (21) for ginseng were not observed in rhubarb. The differences are possibly due to host peculiarities of structure. Lebert and Cohn (19) state that the conidiophores emerge through the stomata in cactus. The same is generally considered true for other species of parasitic oomycetes.

MORPHOLOGY OF THE PENNSYLVANIA RHUBARB PHYTOPHTHORA

It is unnecessary to go into detail regarding the morphology of the Phytophthora associated with the rhubarb crown rot in Pennsylvania except to give the comparisons leading to the conclusion that the species is *P. cactorum*. The fact that the antheridia lie at the side of the oogonia (Plate V, Figs. 15, 16 and 17) places the fungus in the *cactorum* group of the genus Phytophthora (22). The absence of chlamydospores excludes identity with *P. nicotianae* Van Breda de Haan, while the prominence of the papillae and less importantly the spore measurements in rhubarb organism are not in agreement with *P. syringae* Klebahn (18). This leaves *P. cactorum* (Leb. & Cohn) Schroet. and *P. fagi* Hartig, the two names being given as synonymous by Saccardo (23), concerning whose morphological similarity or dissimilarity to the rhubarb fungus there would appear to be any room for doubt. For the purpose of comparison the following table of averaged measurements is submitted:

	Diameter of oospores	Conidia	
		Length	Width
P. fagi measurements by Rosenbaum (22)	30.22μ	33.65μ	25.67μ
P. cactorum from ginseng, by Rosenbaum	27.36	36.62	26.06
P. cactorum from apple, by the writer	26.2	34.4	24.9
Rhubarb Phytophthora, Philadelphia Co., Pa., grown on lima-bean agar slant, by writer	26.2	32.34	25.97
Rhubarb Phytophthora, Philadelphia Co., Pa., second strain grown on cornmeal agar plate, by writer	26.3	37.00	27.5
Rhubarb Phytophthora, Centre Co., Pa., third strain grown on oatmeal agar, by writer	26.6	33.8	25.2

The writer's figures are based on 200 measurements in most cases, and sometimes on 400. There are no significant differences between the averages of Rosenbaum and those of the writer; no differences that would not be accounted for by variations in sampling, the personal factor, the influence of the substratum which is important in the case of conidia, or possibly by strains differing slightly morphologically. There is satisfactory agreement between the measurements of *P. cactorum* from apple and the rhubarb Phytophthora, both being made by the writer. This agreement is supported by the fact that the fungus from apple possesses the power to infect rhubarb and to cause a crown rot. However, the results of the infection experiment insofar as they have progressed reveal a somewhat less degree of virulence on the part of the parasite from apple (see Table I), so there may possibly be certain biologic differences between the two strains of the species. It is interesting to note in this connection that Hartley (10) was unable to infect seedlings of jack pine with *P. cactorum* from ginseng, and this author states further that there is certainly

Table II. The Comparative Effects of Temperature and Media upon the Species of Phytophthora from Rhubarb

Medium and temperature	*Phytophthora parasitica* var. *rhei* Godfrey	Phytophthora sp. from Illinois rhubarb	*Phytophthora cactorum*
Lima-bean agar 7-9° C. 7-day period	No growth	No growth	Mycelium grew 23 mm., no aerial growth or spore development
Oatmeal agar 9-10° C. 6-day period	Mycelium grew 5-6 mm.		Mycelium grew 25 mm., oogonia and antheridia developed, oospores in two weeks
Potato-glucose agar 10° C. 10-day period	Mycelium grew 8 mm.	Mycelium grew 7 mm.	Mycelium grew 17 mm., considerable aerial growth, no spore development
Oatmeal agar 15° C. 14-day period	Growth slow with considerable aerial mycelium, a few chlamydospores		Growth moderately fast, no aerial mycelium, oospores very numerous, conidia few
Potato-glucose agar 16-18° C. 10-day period	Mycelium grew 15 mm., some aerial growth, a few chlamydospores and conidia	Mycelium grew 18 mm., surface growth forming pseudoparenchyma, some aerial mycelium, few conidia and chlamydospores	Mycelium grew 30 mm., rather heavy growth of white aerial mycelium, few conidia or oospores
Cornmeal agar plates 22-23° C.	Mycelium grew 100 mm. in ten days, conidia and chlamydospores rare	Mycelium grew 38 mm. in ten days, chlamydospores rare, a few conidia of small form	Mycelium grew 87 mm. in ten days, oospores and conidia quite numerous
Oatmeal agar 22-23° C.	Growth fairly rapid with considerable aerial mycelium, oospores in two months	Growth fairly rapid, aerial mycelium heavy and tenacious, no oospores ever developed	Growth rapid, little aerial mycelium, oospores and conidia numerous
Lima-bean agar 22-23° C.	Chlamydospores very numerous, conidia fairly so, oospores after two months	Chlamydospores very numerous, conidia fairly so, no oospores ever developed	Growth more rapid than in other species, many oospores and conidia
Lima-bean agar 25° C. 15-day period	Growth rapid, considerable aerial mycelium, Chlamydospores numerous, conidia less so	Growth rapid, considerable aerial mycelium, conidia formed in a few days, Chlamydospores few	Temperature optimum for mycelial growth, there being heavy development, conidia numerous but oospores relatively few
Cornmeal, Lima-bean and Potato-glucose agars 27° C. 8-day period	No distinction in rapidity of growth, moderate development of aerial mycelium	No distinction in rapidity of growth, moderate development of aerial mycelium	No distinction in rapidity of growth, moderate development of aerial mycelium except on corn meal agar
Oatmeal agar 20-30° C. 6-day period	Mycelium grew 33 mm., prominent white aerial growth, no spore development		Mycelium grew 20 mm., some aerial development, no spore formation
Lima-bean agar 31.5° C. 6-day period	Mycelium grew 28 mm., considerable aerial growth		Mycelium grew 8 mm., all surface growth
Oatmeal agar 33° C. 6-day period	Mycelium grew 30 mm., aerial growth prominent	Mycelium grew 30 mm., prominent aerial growth	Growth almost imperceptable
Oatmeal agar	Thin surface growth progressing 12 mm. Godfrey says the maximum for this species is 36° C.	Thin surface growth progressing 13 mm.	No growth

no fungus in America that causes the damage to forest seedlings attributed to *P. fagi* so frequently in Europe. It appears probable therefore that *P. fagi* of Europe is at least biologically distinct from *P. cactorum* of America, although the morphological distinctions cannot be considered as significant.

The culture of *P. cactorum* from apple was compared with those from rhubarb on the following media: cornmeal, oatmeal, lima-bean and potato-glucose agars, and sterilized string bean pods. There appeared no appreciable differences in macroscopic growth, or in the relative production of oospores or conidia. The cultures from rhubarb rotted apples readily and attacked potato tubers and tomato fruit readily in moist chambers.

The foregoing facts leave no doubt that the Phytophthora found parasitizing rhubarb in Pennsylvania is identical morphologically with *P. cactorum* attacking apples, pears, and ginseng in America, and species of cactus in Europe, and that the rhubarb fungus also holds the same close relationship or identity with *P. fagi* which destroys various forest seedlings in Europe.

SUMMARY

PART I. *Phytophthora cactorum* is the cause of a crown rot of rhubarb in Pennsylvania, and probably in other states. The disease is characterized by a brown discoloration and a rotting of tissues in the roots, the crown and the bases of the leaf stalks. The leaves collapse and the death of the plants usually follows.

In old established fields the loss from crown rot may not be great from year to year following infestation, but severe loss of stand results when crowns from infested fields are divided and used to set new fields. The critical periods for disease development occur during warm, wet, cloudy weather in July and August.

Plants from infested fields should not be used to establish new fields. Stock started from seed under disease-free conditions or taken from an old healthy field should be obtained.

Bordeaux mixture sprayed into the crowns and over the petioles promises to be an effective method of preventing the spread of the disease in summer, but will not prevent the decay and death of plants in which the disease has become established.

Roguing and destroying infected plants early in the season seems advisable. Disinfection of dormant roots as a precautionary measure may be carried out.

PART II. In outstanding symptoms, the disease caused by *P. cactorum* is similar to the "foot rot" of rhubarb caused by *P. parasitica* var. *rhei* which has been described currently by G. H. Godfrey. The noteworthy differences include a higher temperature adaptation and a somewhat more rapid progress of disease on the part of the latter during hot weather. There appears to be little difference in the ultimate damage that the two parasites may cause.

The first mention is made of a disease of rhubarb called "foot rot" in southern Illinois. The symptoms of this disease have been found to conform essentially with those produced by *P. cactorum* or *P. parasitica* var. *rhei*, but from specimens of this "foot rot" a third species of Phytophthora parasitic to rhubarb has been isolated. The principal characters distinguishing this species from the other two are more elongate conidia, a high per cent of which are pyriform or irregular in shape.

That the Phytophthora associated with crown rot is pathogenic to rhubarb and is probably identical with the species parasitizing apples, pears and ginseng has been demonstrated in the present investigation.

P. cactorum probably enters the tissues of rhubarb through wounds in most cases, but under very favorable conditions of temperature and moisture the penetration of leaves, petioles and buds without wounds is possible.

Within the host, the mycelium is intercellular with haustoria, although in late stages of decay some hyphae develop within the cells. Saprophytic species of bacteria, Fusarium, and other fungi follow the invasion of the Phytophthora. Colletotrichum very frequently accompanies crown rot, infecting the weakened leaf stalks and seeming to be the chief cause of the damage observed.

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